Johnson

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

JUN 08 1981

Reply to Attn of GP-4

TO: NST-44/Scientific and Technical Information Division
Attn: Shirley Peigare

FROM: GP-4/Office of Assistant General Counsel
for Patent Matters/Nancy L. Fonseca

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP-4 and Code NST-44, the attached NASA-owned U.S. Patewnt is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 4,237,662

Government or
Corporate Employee : Government

Supplementary Corporate
Source (if applicable) :

NASA Patent Case No. : MSC-16,217-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES ☐ NO ☒

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of..."

Enclosure

JUN 1981

(NASA-Case-MSC-16217-1) STRUCTURAL MEMBERS, METHOD AND APPARATUS Patent (NASA) 21 p CSCL 13B

N81-27323

Unclas
00/31 25301

MSC-16,217-1

United States Patent [19]

Kinzler

[11] **4,237,662**

[45] **Dec. 9, 1980**

[54] **STRUCTURAL MEMBERS, METHOD AND APPARATUS**

[75] Inventor: **Jack A. Kinzler**, Seabrook, Tex.

[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics & Space Administration**, Washington, D.C.

[21] Appl. No.: **893,383**

[22] Filed: **Apr. 4, 1978**

[51] **Int. Cl.**[3] **E04N 12/18**

[52] **U.S. Cl.** **52/108**; 52/745

[58] **Field of Search** 52/108, 741, 745; 242/54 A

[56] **References Cited**

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Primary Examiner—Carl D. Friedman

Attorney, Agent, or Firm—Edward K. Fein; John R. Manning; Marvin F. Matthews

[57] **ABSTRACT**

Disclosed are a structural member, such as a truss, and a method and apparatus for fabricating the same from flexible sheet material in compacted form. A plurality of generally tubular columns are progressively formed from the sheet material and deployed generally parallel to one another. Adjacent pairs of the columns are interconnected by respective side members, each of which is comprised of a strip of the sheet material. The sheet material is fastened together by self-attaching fasteners integrally formed from the sheet material of the columns and side members themselves.

60 Claims, 21 Drawing Figures

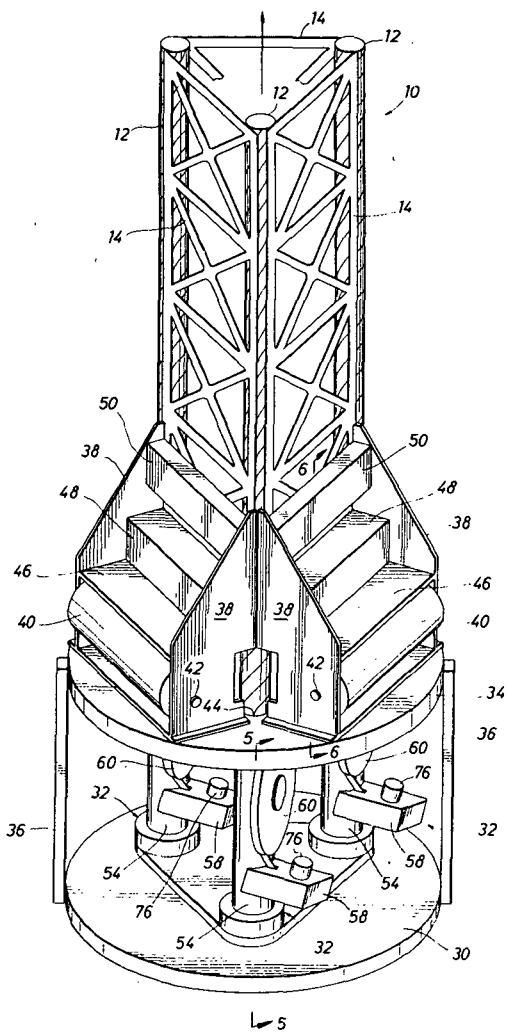


FIG. 5

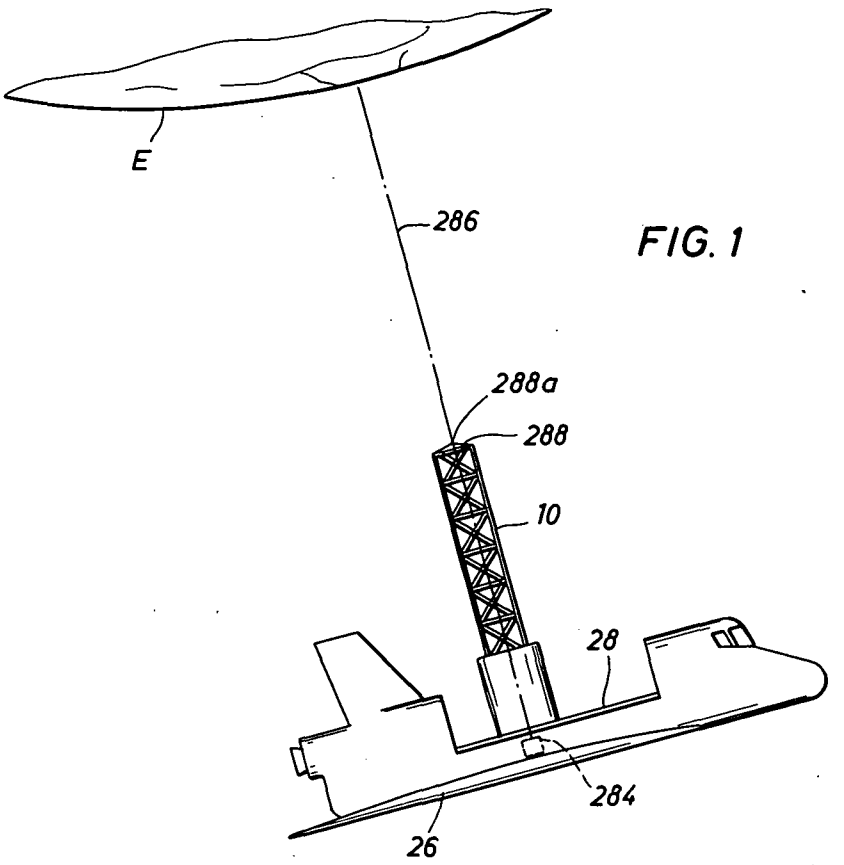

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FIG. 1

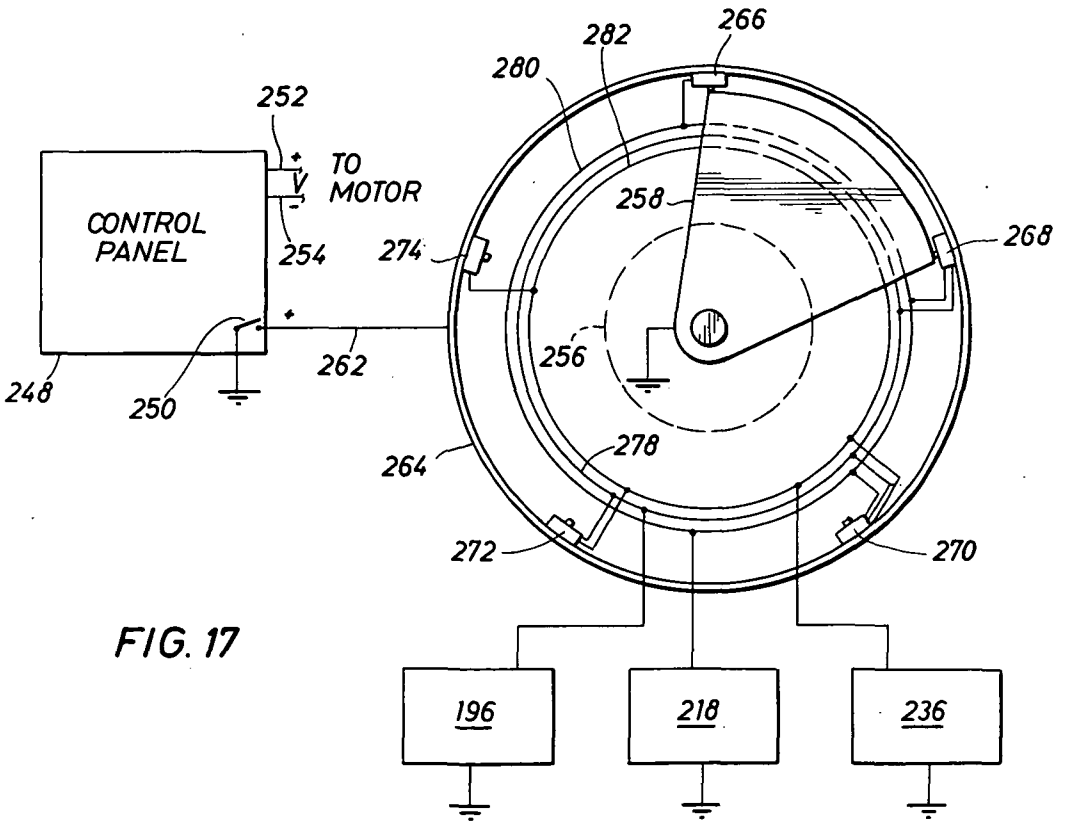

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FIG. 17

FIG. 2

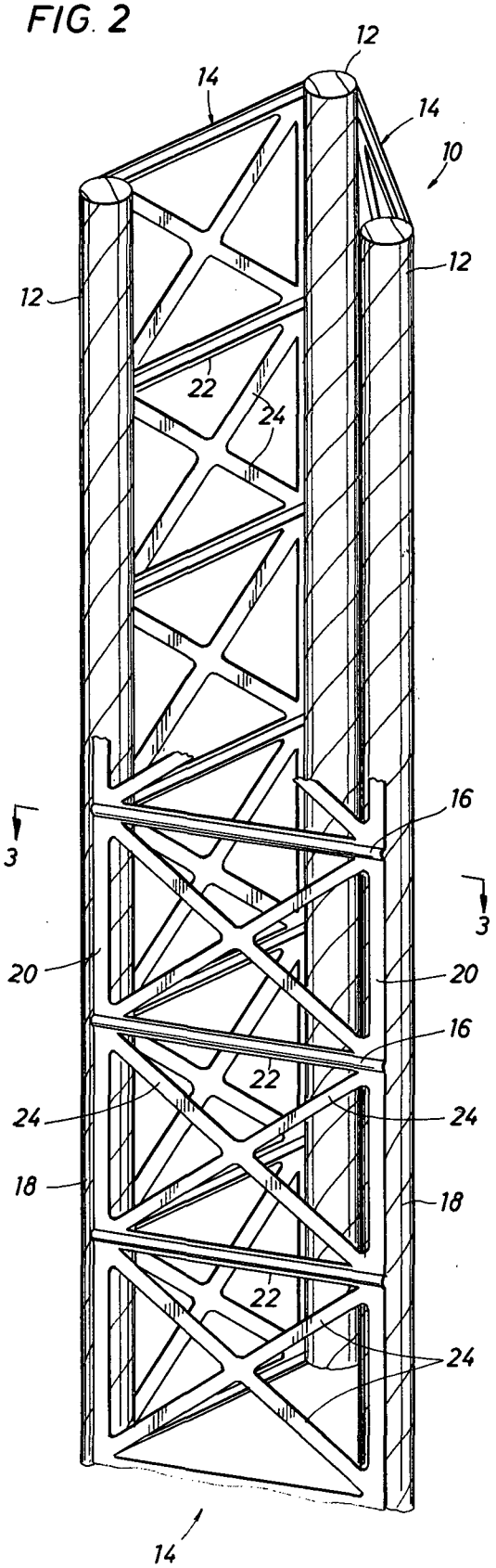
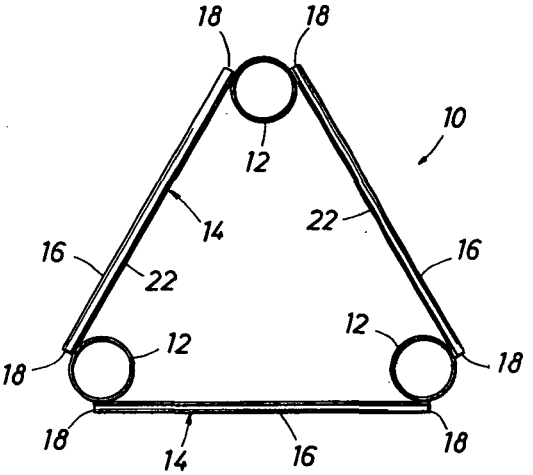


FIG. 3



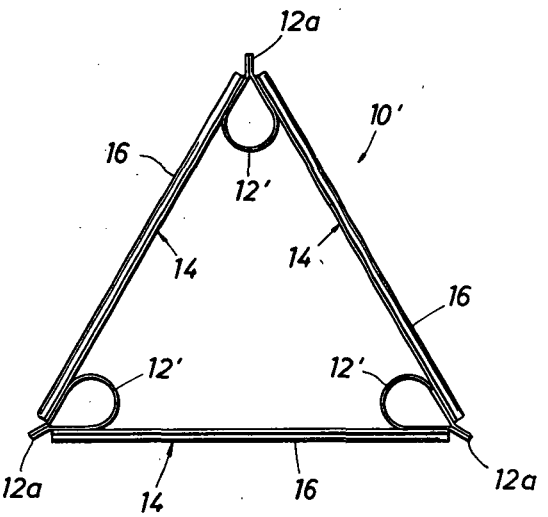


FIG. 3A

FIG. 4

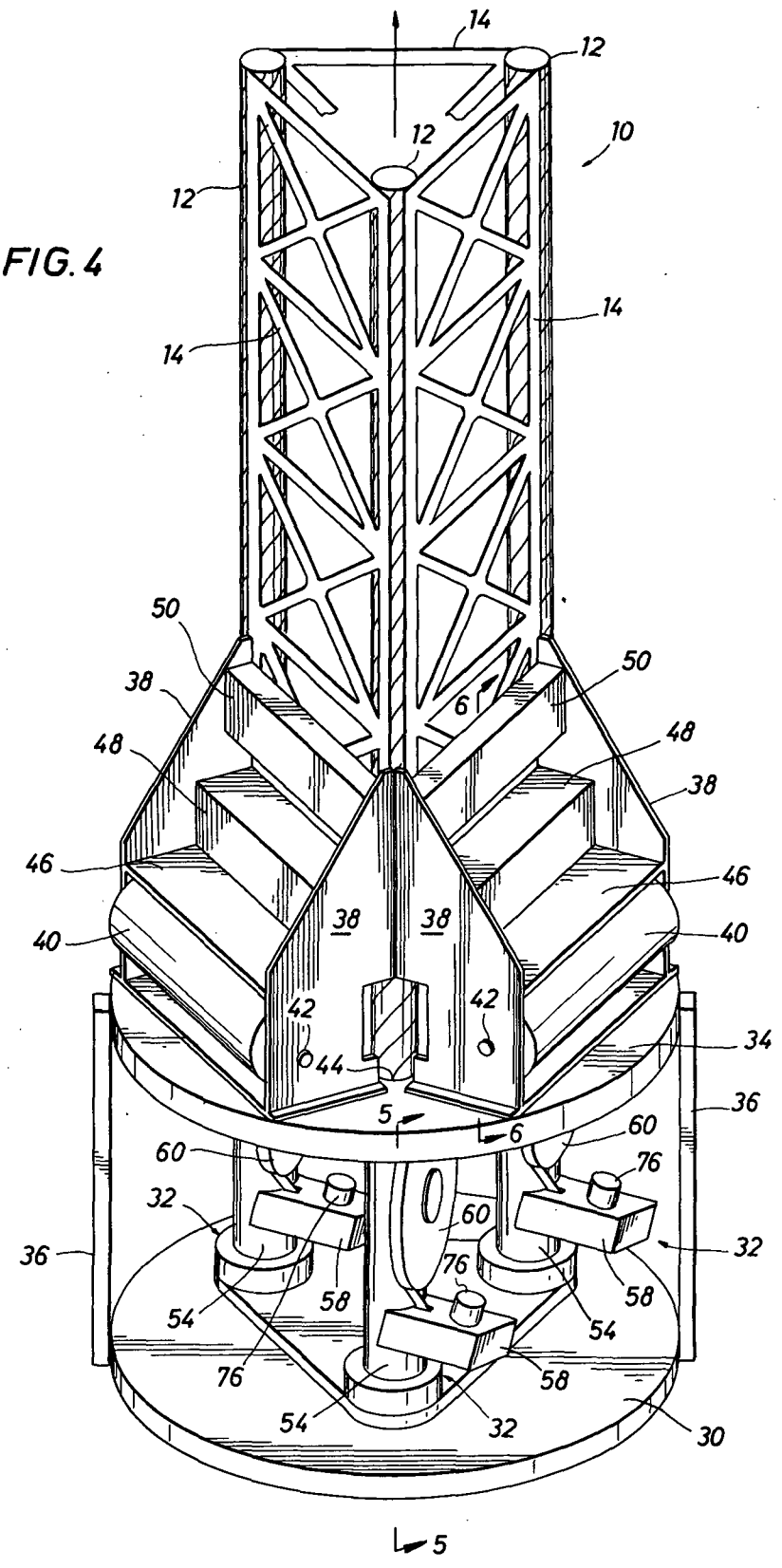
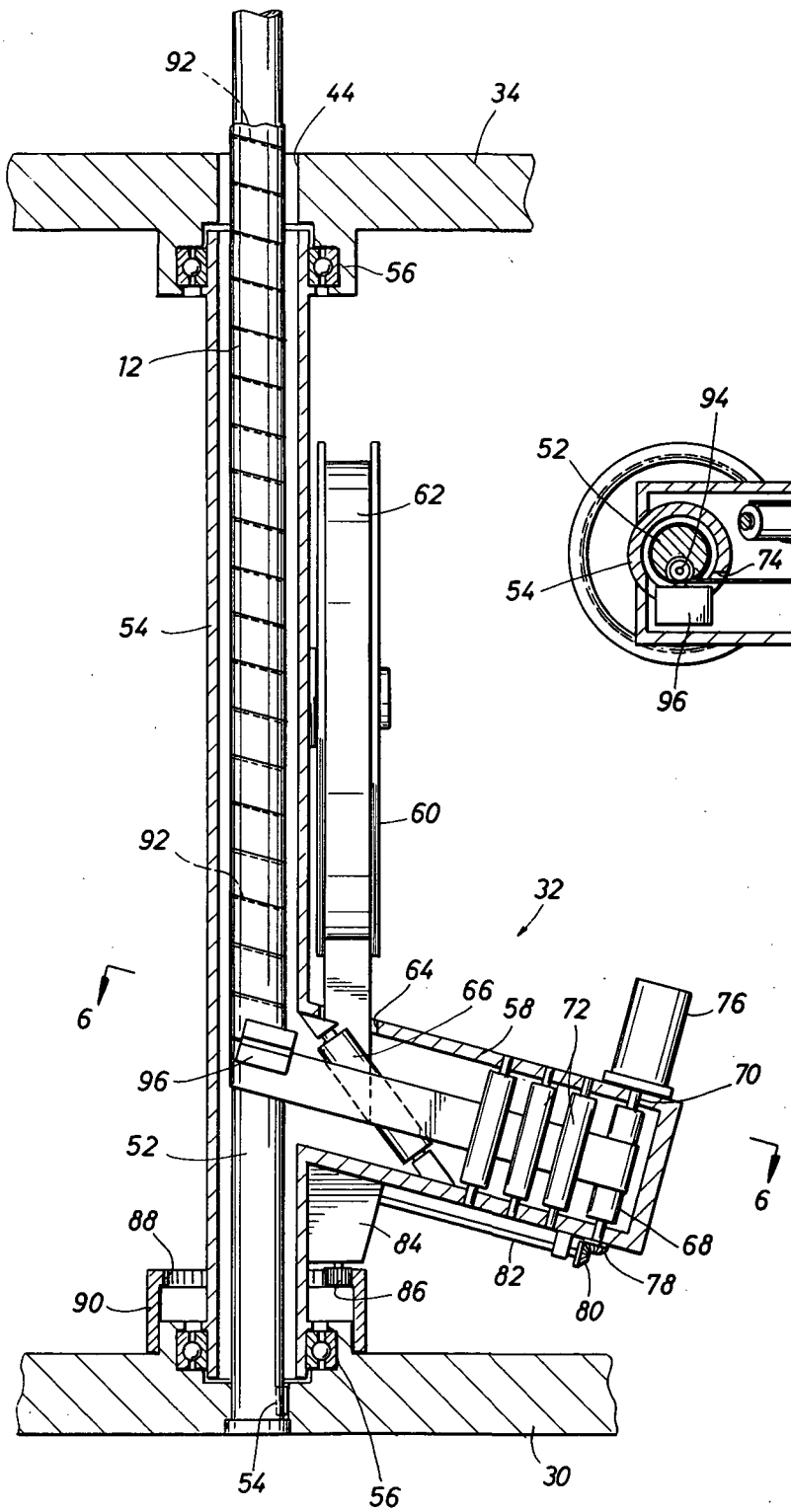

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FIG. 5


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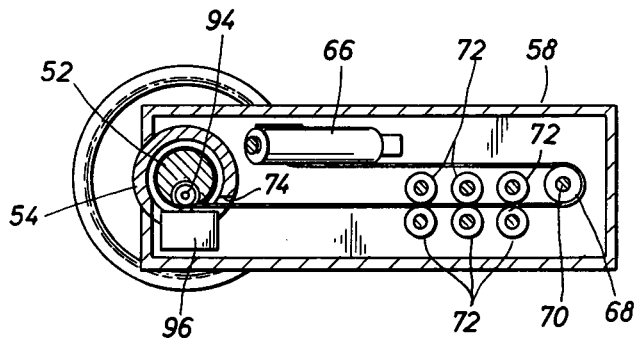

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FIG. 6

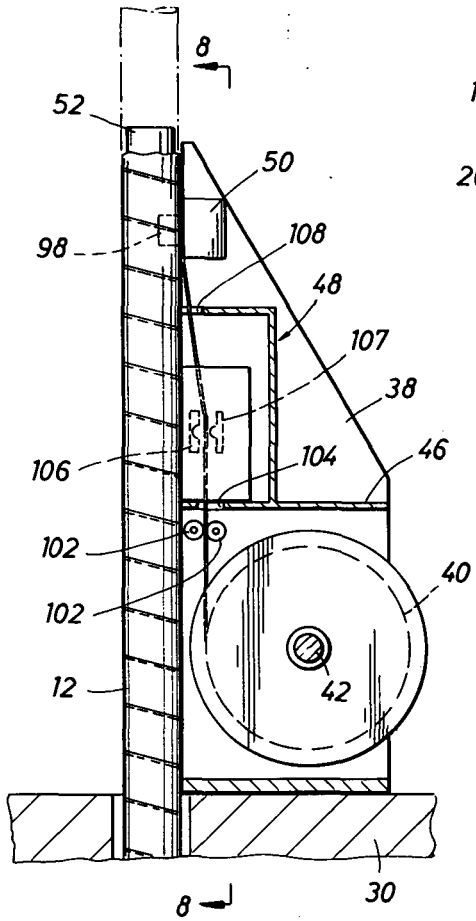

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FIG. 7

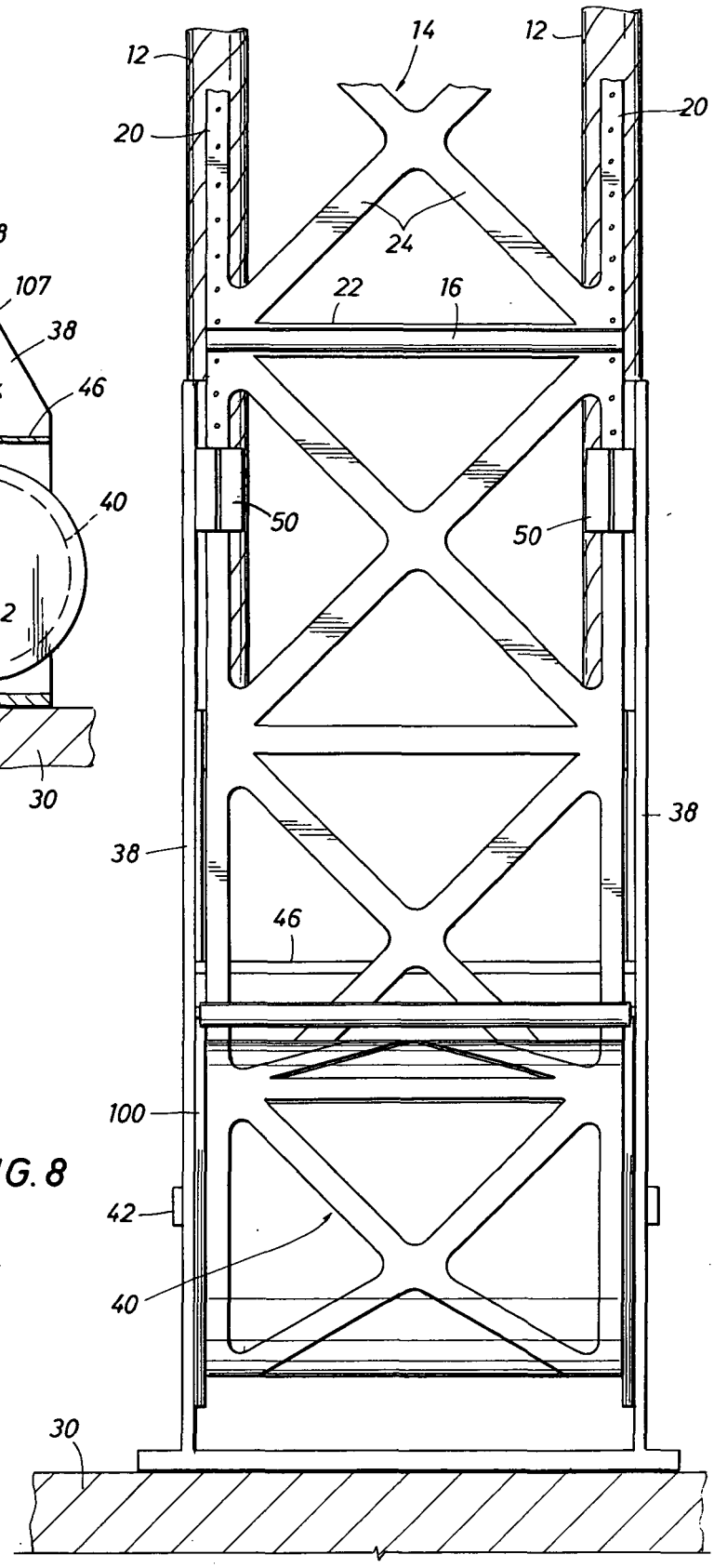

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FIG. 8

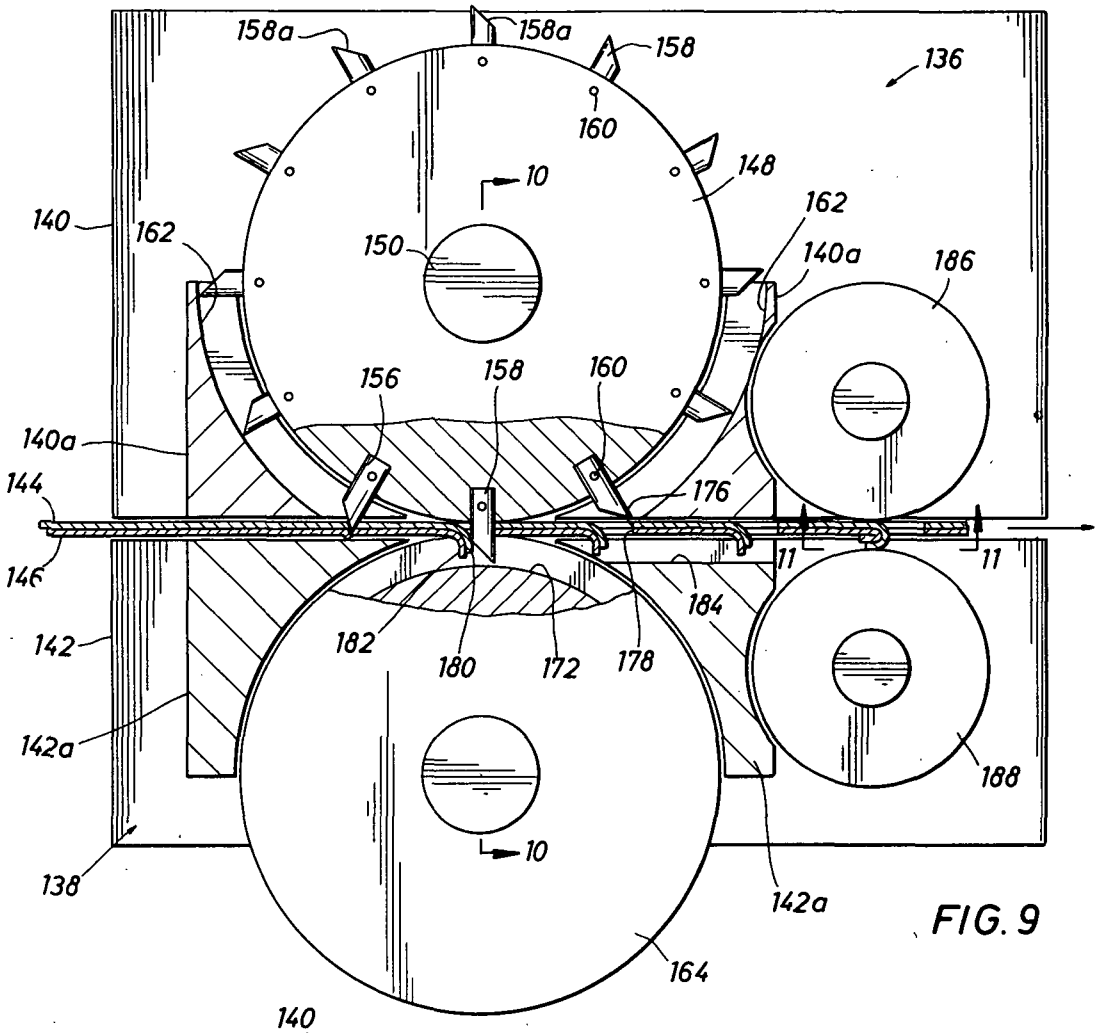


FIG. 9

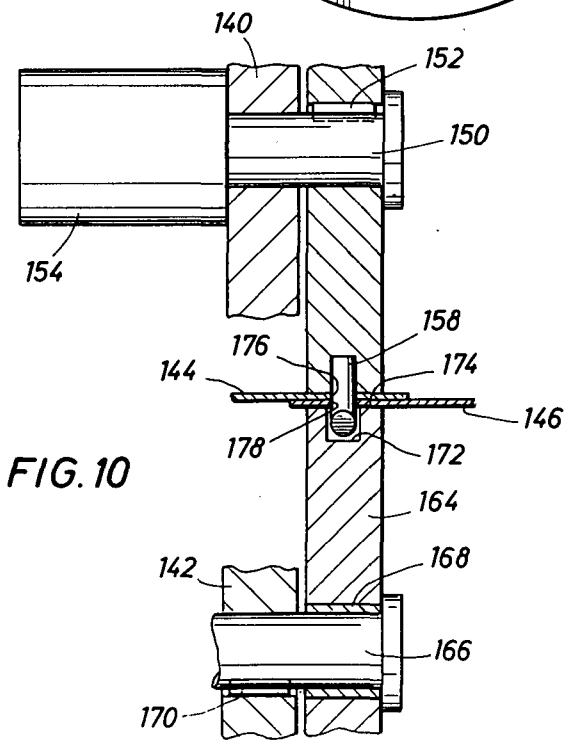


FIG. 10

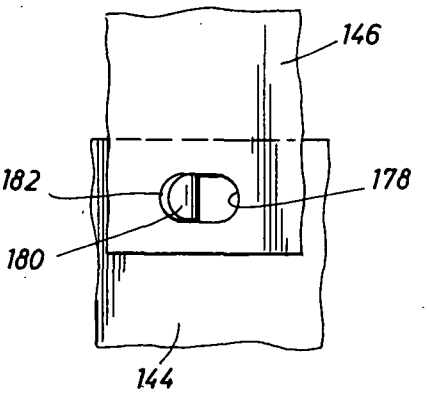


FIG. 11

FIG. 12

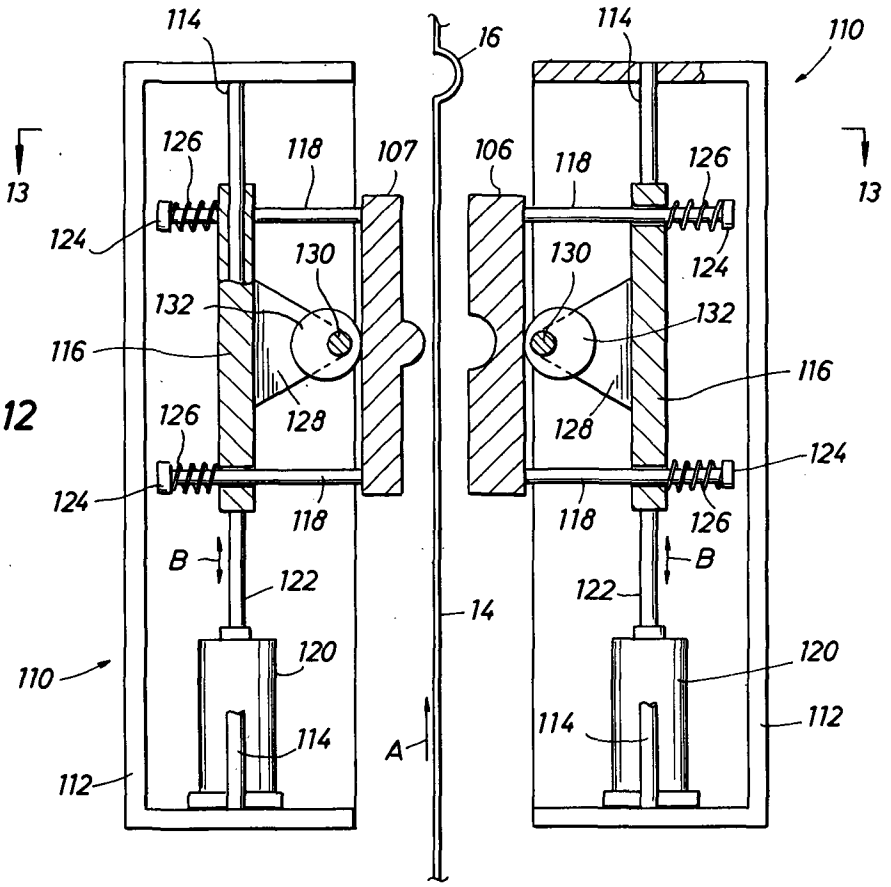

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FIG. 13

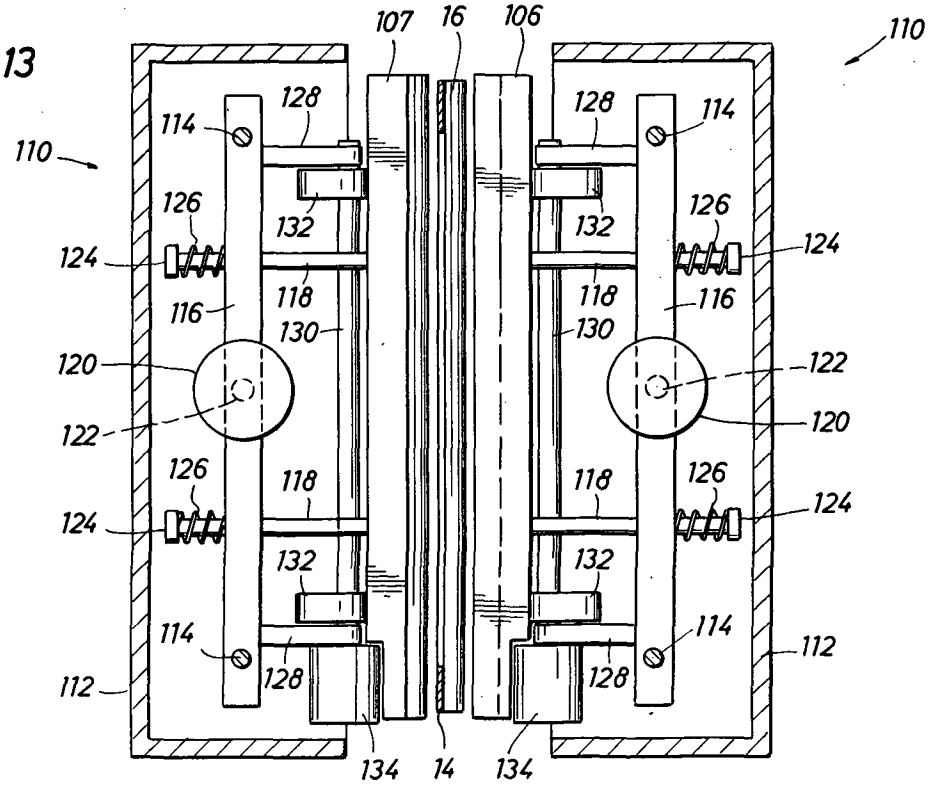

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FIG. 14

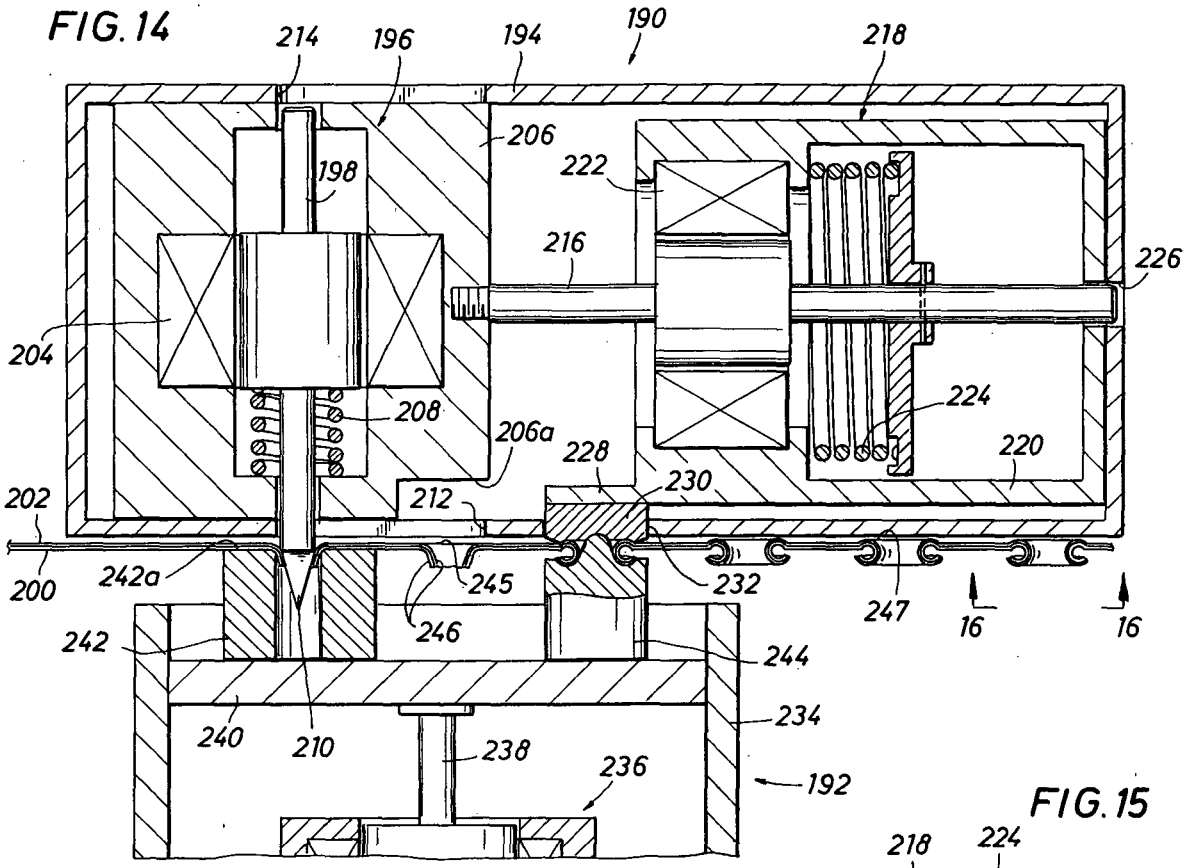


FIG. 15

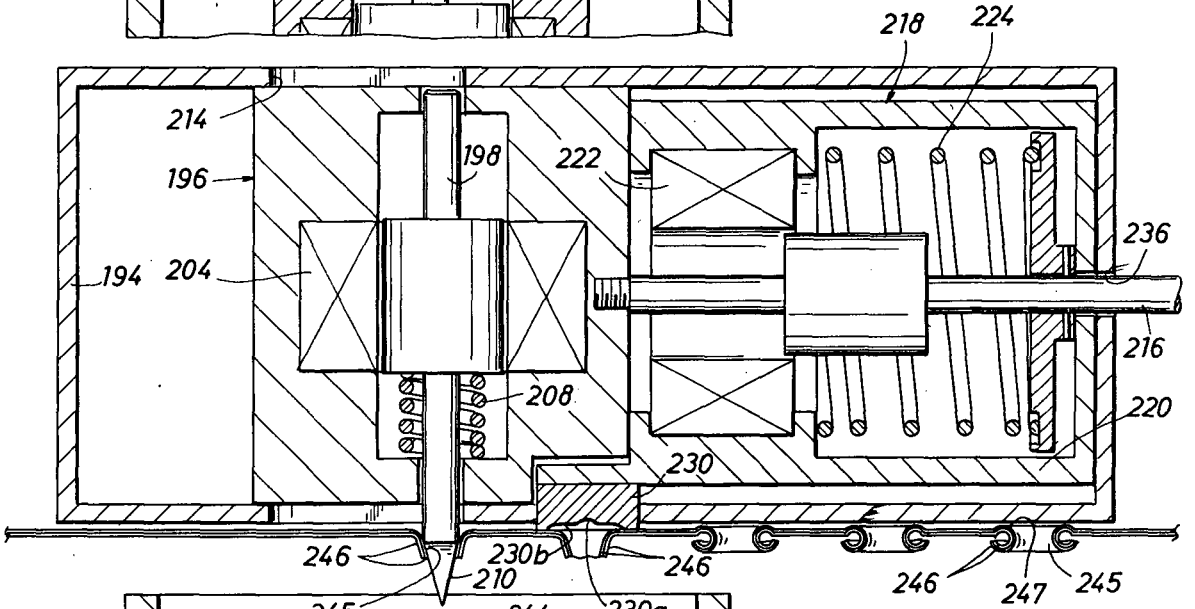


FIG. 16

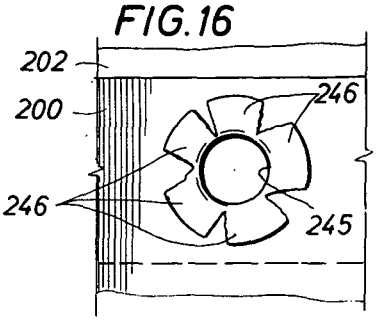
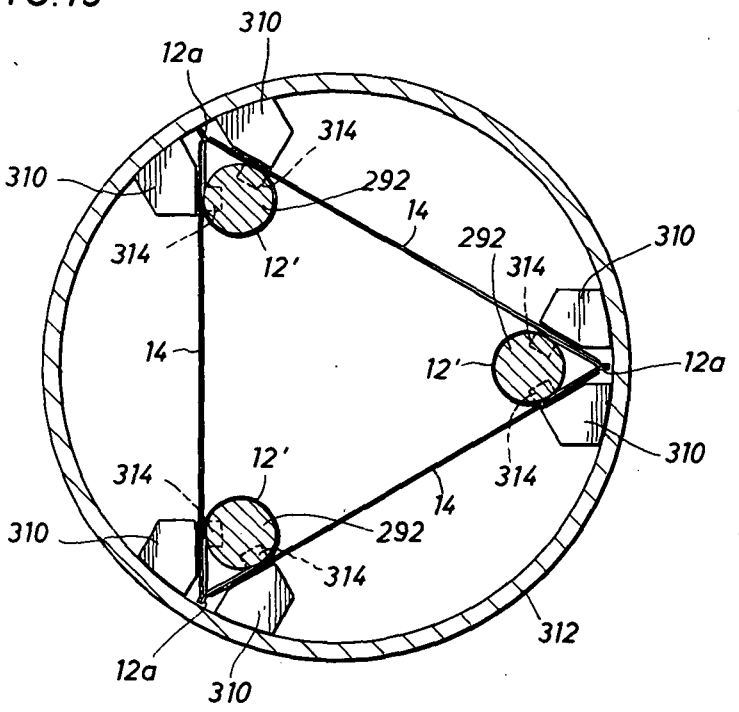


FIG. 19



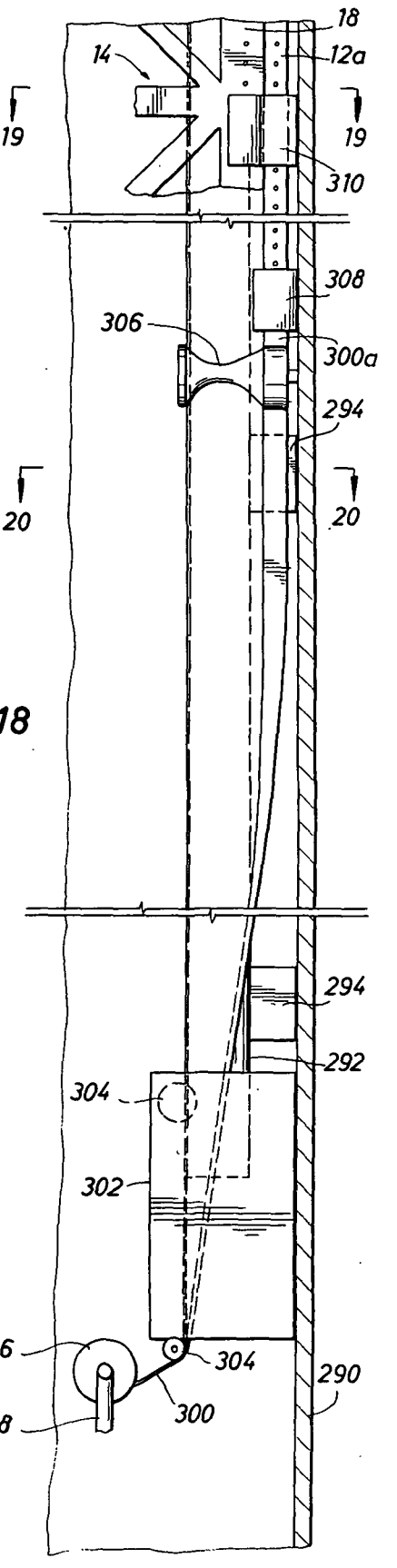
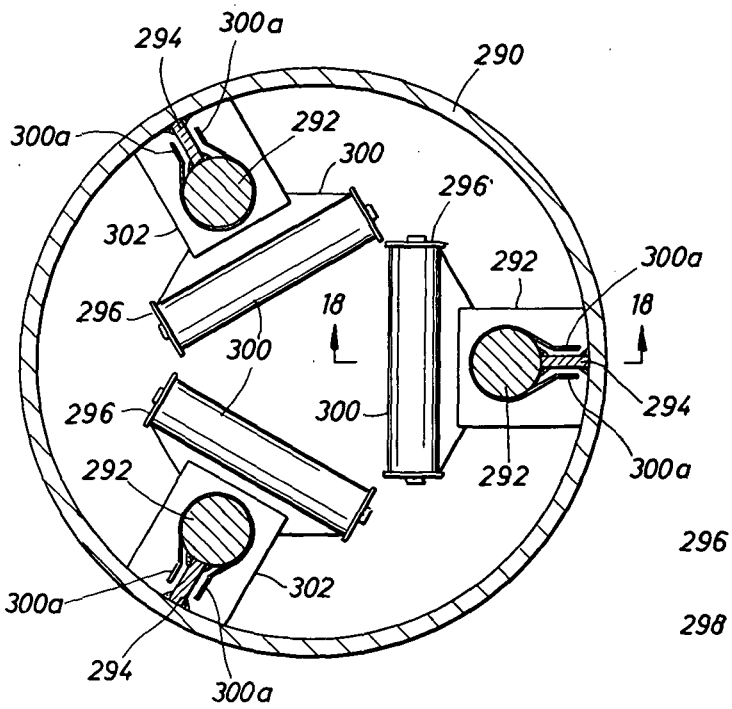


FIG. 18

FIG. 20



STRUCTURAL MEMBERS, METHOD AND APPARATUS

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the fabrication of structural members such as trusses, particularly for use in space. The usefulness of large orbiting space structures such as solar energy collecting stations and various other types of space stations is now widely recognized. In constructing such structures, it is impracticable to transport the building materials to the space construction site in the form of completed structural units such as trusses. Only relatively few such units could be transported in a single trip of the space shuttle or other vehicle. Thus the cost of transporting enough units to construct a large space structure would be prohibitive.

It is thus extremely important that techniques be developed for forming the structural units in space and that the construction materials be transported into space in the most compact form possible. At the same time it is necessary that these materials be as lightweight as possible and that the amount of material needed to construct a given item be minimized.

It thus becomes readily apparent that conventional construction materials, such as dense, rigid metal beams, plates, and the like are not practical for use in such projects. However, the environment of space with its low gravitational forces and relative freedom from airborne chemicals of various kinds permits the use of unique construction materials which would be unsuitable for like use on earth.

The use of such different materials, along with the differences in the space environment, in turn make the construction techniques conventionally used on earth impractical for use in space, and drastically different methods are indicated. Among the requirements of such different methods are that the fabrication process be as fully automated as possible and that the amount of additional material needed to fasten various component elements together be minimized.

2. Description of the Prior Art

U.S. Pat. Nos. 3,961,738 and 3,840,960 each disclose somewhat automated devices for manufacturing structural units. However, neither the raw materials, the manufacturing devices, nor the finished products as well suited for use in space. The raw materials include metal of substantial density and inherent rigidity, and the manufacturing methods and devices are adapted to these materials rather than to the types which are preferably used to form structural members for use in space. The finished products are likewise heavier than is proper for space structures. The techniques disclosed also involve numerous other features which would be undesirable for space use. For example, the device of U.S. Pat. No. 3,961,738 requires a separate connecting medium, namely a welding material, which constitutes additional weight and takes up additional space.

U.S. Pat. Nos. 3,740,812, 3,768,130, and 2,141,642 also disclose techniques for forming structural units which make some attempt to minimize the number of separate parts which must be attached together. However, again each of the prior patents is unsuitable for space use because of the rigidity and/or weight of the initial materials and/or the need for separate connecting elements or media.

U.S. Pat. Nos. 2,316,349 and 3,940,962 suggest means for forming cylindrical members from sheet material. The latter of these two patents also suggests means for fastening metal without additional connecting means, as do U.S. Pat. Nos. 3,722,280 and 3,470,596. However, none of these prior patents disclose apparatus which is well suited for use in space, nor are they suggestive of a total scheme for forming a structural member such as a truss.

SUMMARY OF THE INVENTION

The present invention comprises an apparatus and method of forming a structural member such as a truss, as well as the structural member itself. The method and apparatus of the invention are particularly suited for use in space in that they use as the basic construction material lightweight flexible sheet material in compacted form. Such material optimizes both the space and weight factors thereby permitting enough material for a substantial amount of construction to be carried on one trip of the transport vehicle.

Once the vehicle has reached the construction site, one or more structural members may be formed by a fully automated apparatus which minimizes the need for extra-vehicular activities by personnel. In particular, the truss-forming apparatus may remain in a suitable bay in the transport vehicle and the truss may be progressively formed by such apparatus and deployed from the bay.

In the preferred forms of the invention, the flexible sheet material is stored on or in the forming apparatus in compacted form, e.g. roll form. Column-forming means progressively form a plurality of tubular column members from respective strips of the sheet material and deploy these column members generally parallel to one another. Adjacent pairs of the column members are interconnected by progressively securing a respective side member, comprised of a respective strip of the sheet material, between each such pair of column members.

The sheet material from which the structural member is made is much more flexible and less dense than the materials used in constructing structural members for use on earth. However, the manner in which such sheet material is formed into the structural member permits the latter to withstand extremely high loading, particularly in comparison with its own weight. For example, while the sheet material per se is inherently flexible, in the ordinary sense of the word, the structural member formed therefrom is substantially rigid, i.e. capable of maintaining its form under significant loads. In the uses for which such structural members are primarily intended, the main type of loading encountered will be endwise compressive loading. The tubular form of the column members enables them to withstand endwise compressive loads far exceeding their own weights.

The weight of the sheet material from which the structural members are fabricated may be further reduced by pre-cutting the strips of sheet material from which the side members are to be made to form inter-

connected strips to serve as compression and tension struts. Such struts provide ample structural strength for the structural member, yet the removal of the excess material therebetween substantially reduces the weight of the construction material needed for each member. The resulting open areas also enhance the thermal expansion characteristics of the finished truss by permitting exposure of all sides to the sun's rays. The compressive strength of each of the compression struts may be further enhanced by forming an elongate bead thereon.

The present invention further reduces the weight of the raw material which must be carried to the construction site in space by providing for the securing together of overlapping layers of the sheet material by self-attaching tabs formed from the main bodies of the sheet material itself. Thus no separate connecting members or media, such as welding material, staples, adhesive, or the like, need be carried by the transport vehicle nor are any wasteful by-products produced. These self-attaching tabs may be used not only to fasten the side members to the column members of the structural member, but also to fasten the sheet material of each individual column member upon itself. In the preferred forms of the invention, the apparatus for forming such tabs also serves to advance the sheet material during the progressive formation of the structural member.

Several special techniques may be employed to see that the structural member is kept straight as it is progressively formed. This is especially important as it is anticipated that the individual structural members will be much longer than their earth-borne counterparts. One of these techniques is to deploy the structural member toward the earth. While the environment of the construction site may be considered "weightless" for most purposes, the slight amount of the earth's gravity which is exerted, in the absence of other substantial gravitational forces, can have a significant effect on the path in which the structural member is progressively deployed and thus on its straightness.

Another technique which may be used in this connection is the sensing of a target mounted on the end of the structural member and movable therewith. By comparing this target with a suitable reference, it is possible to detect slight deviations before they advance to a harmful degree. One way of providing for such compensation is to provide separate variable speed motors for the forming mechanisms for the respective column members and selectively varying their speeds to control the direction of deployment of the structural member.

Accordingly, it is a principal object of the present invention to provide a structural member comprised of flexible sheet material and a method and apparatus for forming same.

Another object of the invention is to provide an automated apparatus for forming such a structural member.

A further object of the invention is to provide a structural member, method, and apparatus therefor which are particularly suited for use in space.

Still another object of the invention is to provide a means for attaching overlapping layers of sheet material without the use of separate connecting media.

Another object of the invention is to provide means for guiding the direction of progressive formation of a structural member.

Still other objects, features, and advantages of the present invention will be made apparent by the following description of the preferred embodiments, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is an elevational diagrammatic view of a structural member being deployed from a space vehicle in accord with the invention.

FIG. **2** is a perspective view of a structural member according to the invention with parts broken away.

FIG. **3** is a transverse cross-sectional view taken on line **3—3** of FIG. **2**.

FIG. **3A** is a view similar to that of FIG. **3** of a second form of the structural member.

FIG. **4** is a perspective view of the apparatus for forming the structural member of FIGS. **2** and **3**.

FIG. **5** is a longitudinal cross-sectional view of one of the column-forming assemblies of the apparatus of FIG. **4**.

FIG. **6** is a cross-sectional view taken on line **6—6** of FIG. **5**.

FIG. **7** is a sectional view taken on line **7—7** of FIG. **4** and including one of the bead-forming assemblies and one of the fastening assemblies for the side members.

FIG. **8** is a view taken on line **8—8** of FIG. **7**.

FIG. **9** is an enlarged view partly in section and partly in elevation of one form of fastening assembly.

FIG. **10** is a view taken on line **10—10** of FIG. **9**.

FIG. **11** is a plan view of one of the self-fastening means formed by the assembly of FIGS. **9** and **10**.

FIG. **12** is an enlarged view partly in section and partly in elevation of one of the bead-forming assemblies.

FIG. **13** is a view taken on line **13—13** of FIG. **12**.

FIG. **14** is an enlarged sectional view of a second type of fastening assembly.

FIG. **15** is a view similar to that of FIG. **14** showing the movable parts in a different position.

FIG. **16** is a plan view of one of the self-fastening means formed by the assembly of FIGS. **14** and **15**.

FIG. **17** is a schematic depicting the sequencing means for the assembly of FIGS. **14** and **15**.

FIG. **18** is a longitudinal view partly in section of a column-forming assembly for forming the type of column shown in FIG. **3A** taken on line **18—18** of FIG. **20**.

FIG. **19** is a transverse sectional view taken on line **19—19** of FIG. **18**.

FIG. **20** is a transverse sectional view taken on line **20—20** of FIG. **18**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawing, FIGS. **2** and **3** illustrate a structural member, in particular a truss **10**, according to the present invention. The truss **10** is formed of sheet material which is, per se flexible. However, the sheet material is formed into a truss in such a way that the finished product is essentially rigid. While flexibility and rigidity are technically relative qualities, the terms "flexible" and "rigid" will be used herein in a common or every day sense. Thus where a substantial length of a sheet material, say one or two meters, will flex under its own weight, e.g. when one end thereof is lifted, or can be easily flexed manually, at earth's gravity, the sheet material will be considered "flexible." On the other hand, the finished truss of the length desired for use in a space construction project, is capable of substantially maintaining its configuration without readily noticeable deformation under at least its own weight, whether loaded endwise as a column or laterally as a beam, and would be considered "rigid."

One example of a preferred type of sheet material for the formation of the trusses of the present invention is sheet aluminum. Aluminum rolled stock ranging in gauge from about 0.01 cm. (0.004 in.) to 0.03 cm. (0.012 in.) has been successfully tested for use in the present invention. Other examples of suitable sheet materials are thermoplastic materials such as polysulfones as well as plastic laminates, either "pre-preg" or finished. Each of these materials has a number of characteristics which are desirable in connection with the present invention. In particular, they are essentially flexible, yet not too flexible to prevent their formation into an essentially rigid finished product. Their flexibility permits them to be stored in compacted form, e.g. on rolls, in the transport vehicle. The preferred materials are also of relatively low density, as compared to conventional construction materials such as steel. Thus sufficient material for a substantial amount of construction may be transported to the space construction site by a vehicle such as the space shuttle. The flexibility of the material also permits its formation into a truss with light duty equipment.

Referring again to FIGS. **2** and **3**, the truss **10** includes three parallel tubular columns **12**. As used herein, the term "tubular" will be used to denote a structure which is essentially continuous and closed (with the exception of relatively small openings or the like such as might be formed, for example, by the attachment means to be described below), and such terminology is not intended to limit the configuration of the column to a cylindrical form. Each of the columns **12** is formed from a respective strip of sheet material closed upon itself by helical winding and then fastened in a manner to be described more fully below.

Each adjacent pair of the columns **12** is interconnected by a respective side member **14** formed by a respective strip of sheet material. Each side member **14** is substantially planar, with the exception of beads **16**, and is disposed with its opposite side edges **18** adjacent respective ones of the connected pair of columns **12**. Thus the truss **10** is generally triangular in transverse cross-sectional configuration, as best shown in FIG. **3**.

In order to further reduce the weight of the construction material and the finished truss, the side members **14** are precut to remove excess material over and above what is necessary to provide sufficient structural strength in the finished truss. Each side member thus includes a pair of longitudinally extending attachment elements **20** each adjacent a respective one of the side edges **18** and secured to the adjacent column **12**. The pre-cutting also forms a number of strut elements extending generally transversely between the attachment elements and integral therewith. These strut elements include longitudinally spaced apart compression struts **22** disposed substantially perpendicular to the attachment elements **20**. The sheet material of the side members **14** is deformed to provide an elongate bead **16** along each of the compression struts and through the adjacent portions of the attachment elements **20**, i.e. from one side edge **18** to the other. Beads **16** increase the compressive strength of the struts **22**. The strut elements also include a number of tension struts **24** extending diagonally between the attachment elements **20** and the compression struts **22** and integral therewith. In the form of truss shown, there are a pair of crossed tension struts **24** between each adjacent pair of the compression struts **22**. However numerous other arrangements are possible.

The pre-cutting of the side members and the resulting open areas between the struts and attachment elements also enhances the thermal expansion characteristics of the finished truss by permitting at least some direct exposure of each column and side member to solar radiation. This substantially reduces the problem of bending of the truss which might otherwise occur due to disproportionate thermal expansion of opposite sides of the truss, where one side is directly exposed to the sun's rays, and the other side is substantially shielded.

Referring now to FIG. **4**, there is shown an apparatus for progressively forming the type of truss **10** illustrated in FIGS. **2** and **3**. The apparatus is sized to fit in a bay in a suitable transport vehicle, such as the space shuttle **26** illustrated in FIG. **1**. During transport, the apparatus may be disposed in a sideways position in the cargo bay. When the construction site is reached, the doors **28** of the bay may be opened and the apparatus may be raised to an upright position with respect to the shuttle **26** on suitable hinged connections. As the truss **10** is progressively formed, it is deployed outwardly from the shuttle **26**.

The truss-forming apparatus of FIG. **4** includes a base plate **30** on which are mounted three column-forming assemblies **32** each for forming a respective one of the columns **12**. A second plate **34** is supported above the assemblies **32** by a number of spacers, two of which are shown at **36**, interconnecting the plates **30** and **34**. The columns **12** progressively formed by the assemblies **32** are deployed upwardly through apertures **44** in plate **34** for connection to the side members **14**.

Mounted on plate **34** are four pair of brackets **38**. At the bottom of each pair of brackets **38** a roll **40** of sheet material for a respective one of the side members **14** is stored between the brackets **38** and mounted on a respective spindle **42** whose ends are rotatably mounted in respective ones of the pair of brackets **38**. The brackets **38** of each pair are aligned with respective ones of a pair of adjacent columns **12** whereby the respective roll **40** is properly positioned generally parallel to its intended final position interconnecting those two columns.

A shelf **46** is rigidly mounted between each pair of brackets **38** above the respective roll **40**. Mounted on each shelf **46**, and also between the respective pair of brackets **38**, is a bead-forming assembly **48**. Each of the assemblies **48** sequentially forms beads **16** on the sheet material for a respective one of the side members **14** after it is deployed from the roll **40** but prior to its attachment to the columns **12**.

A respective housing **50** is mounted above each of the bead-forming assemblies **48** on and between the respective pair of brackets **38**. Each of the housings **50** encloses at one end a portion of an attaching assembly for progressively securing one of the attachment elements **20** of the respective side member **14** to the adjacent one of the columns **12**. The other attachment element **20** of that side member **14** is similarly secured to its respective column **12** by an identical assembly portion housed in the other end of housing **50**.

Referring now to FIGS. **5** and **6** in conjunction with FIG. **4**, one of the column-forming assemblies **32**, each of which is identical, will be described in more detail. The assembly **32** includes the lower portion of a mandrel **52** rigidly mounted in the base plate **30** to extend perpendicularly therefrom by any suitable means such as a key **54**. Mandrel **52** extends through the aperture **44** in upper plate **34** to support the column **12** for securing to the side members **14**. A sleeve **54** coaxially surrounds

the portion of mandrel 52 between plates 30 and 34. The ends of sleeve 54 are rotatably mounted in respective ones of the plates 30 and 34 by bearing assemblies 56. Extending laterally outwardly from sleeve 54 and integral therewith is a roller housing 58. Housing 58 is not perpendicular to sleeve 54 but rather is angled toward plate 30 from its inner to its outer extremity for a purpose to be described below. A reel 60 is mounted on the exterior of sleeve 54 above roller housing 58 for rotation about an axis perpendicular to that of sleeve 54. Reel 60 stores a roll 62 of sheet material for forming the respective column 12.

The strip of sheet material is threaded from the roll 60 through an aperture 64 in the roller housing 58 and under a first idler roller 66. Roller 66 is rotatably mounted in the housing 58 with its axis at an angle to the sleeve 54, as well as to the direction at which housing 58 extends from the sleeve, such that it changes the orientation of the strip of sheet material from parallel to sleeve 54 to parallel to housing 58. The strip of sheet material next passes away from sleeve 54 and around a drive roller 68 rotatably mounted in the distal end of housing 58 on a shaft 70. Shaft 70 and roller 68 are disposed perpendicular to the direction in which housing 58 extends from sleeve 54. The strip of sheet material next passes back toward sleeve 54 between pairs of opposed idler rollers 72 rotatably mounted in housing 58 parallel to drive roller 68. The strip then passes through an aperture 74 in sleeve 54 and onto the mandrel 52.

An electric variable speed motor 76 is mounted on the exterior of housing 58 and operatively associated with the shaft 70 of the drive roller 68. Shaft 70 extends through housing 58 and has a bevel gear 78 on its end opposite motor 76 and just outside housing 58. Gear 78 engages another gear 80 on the end of a shaft 82 which extends along the exterior of the housing 58 and into a gear box 84 mounted on sleeve 54 below housing 58. Through gears (not shown) in the box 84 torque is transmitted to a spur gear 86 engaging the teeth of a second spur gear 88 formed on the interior of an annular flange 90 rigidly mounted on plate 30 in coaxially surrounding relation to the lower portion of sleeve 54.

It can thus be seen that when the motor 76 is operating, the entire sub-assembly comprising the sleeve 54 and housing 58 along with the various parts mounted thereon is caused to rotate about the mandrel 52 thus wrapping the strip of sheet material around the mandrel 52. Due to the angle at which housing 58 extends from sleeve 54, the strip is helically wrapped with adjacent turns of the helix overlapping along the side edges of the strip of sheet material as indicated in phantom at 92.

The turns of the helix of column 12 are first brought into overlapping relation at the point at which the sheet material first engages the column. Adjacent this point there is a fastening assembly, one sub-assembly 94 of which is mounted within the mandrel 52, and the other sub-assembly 96 of which is mounted on the sleeve 54 adjacent aperture 74 for rotation with sleeve 54. The assembly 94, 96 will be described in detail below. At this point it is simply noted that assembly 94, 96 serves to secure together the overlapping layers of sheet material of column 12 by self-attaching tab means formed from the sheet material itself.

The column 12 thus formed, while comprised of sheet material which per se is flexible, has sufficient rigidity as a column so that, as the sheet material continues to be progressively wrapped around the mandrel 52 and attached upon itself, the column thereabove is forced along the mandrel 52 and deployed toward the fastening assemblies for securing the side members 14 to the column. While roller 68 has been shown as a drive roller, this expedient is not strictly necessary as the wrapping and attaching of the sheet material will in many cases be sufficient to advance the column 12 along the mandrel and to pull additional sheet material from roll 62. However, the provision of a drive connection to roller 68 ensures proper movement of the sheet material. It is also noted that, because the sub-assembly including sleeve 54, housing 58, etc. rotates about mandrel 52, rather than the mandrel 52 rotating within sleeve 54, the column 12 does not rotate as it is deployed along the mandrel 12 thereby facilitating simultaneous attachment of the three columns 12 to the side members 14.

Referring now to FIGS. 7 and 8, there is shown the apparatus disposed between one pair of brackets 38. This apparatus includes a roll 40 of sheet material for a respective one of the side members 14 of the truss, a bead forming assembly 48, and a pair of fastening assemblies each of which comprises sub-assemblies 50 and 98. As best seen in FIG. 8, the sheet material for the side member 14 is pre-cut to remove the material between the strips which are to serve as the attachment elements 20 and struts 22 and 24. The material is then wound on a spool 100 which rotates on a shaft 42 whose ends are mounted in respective ones of the brackets 38. Thus the sheet material is stored on the apparatus for transport to the construction site and subsequent use in forming the truss.

The sheet material is fed from the spool 100 upwardly between a pair of opposed guide rollers 102, through an aperture 104 in plate 46 and into the bead forming assembly 48. Within the assembly 48 a pair of "flying" dies, 106, 107 are cyclically driven, in a manner to be described more fully below, to successively form beads 16 on the compression struts 22 as the sheet material progressively passes through the assembly 48.

After passing through the assembly 48, the sheet material passes upwardly through an aperture 108 in the upper end of the housing of the bead-forming assembly and into the fastening assemblies 50, 98. Each of the fastening assemblies has one of its sub-assemblies 50 mounted on one of the brackets 38 and the other sub-assembly 98 mounted within a respective one of the mandrels 52 in opposition to the respective sub-assembly 50. The sub-assemblies 50 and 98 are thus positioned to fasten a respective one of the attachment elements 20 of the side member 14 to a respective one of the columns 12 in generally tangential relation. Like the fastening assemblies 94, 96 of the column-forming assemblies, fastening assemblies 50,98 operate to form self-attaching tabs from the overlapping layers of sheet material of the respective columns 12 and attachment elements 20 per se, without the use of extraneous fastening means, and further operate to advance the side member 14 and connected columns 12.

Apparatus similar to that shown in FIGS. 7 and 8 is disposed between each of the other two pair of brackets 38 for handling the other two side members 14.

FIGS. 12 and 13 show one of the bead-forming assemblies in greater detail. This assembly includes two sub-assemblies 110, each associated with a respective one of the dies 106, 107. The sub-assemblies 110 are identical in structure and operation except for the fact that one sub-assembly includes female die 106, while the

other includes a male die **107**. Accordingly, all corresponding parts of the two sub-assemblies except for the dies will be given like reference numerals.

The sub-assembly **110** including the female die **106** further comprises a housing **112** having an open side facing toward the sheet material of side member **14**. A pair of guide rods **114** are fixedly mounted in the housing **112** and disposed generally parallel to the direction in which the side member **14** moves through the bead-forming assembly, indicated by the arrow A. A mounting plate **116** is slidably mounted on rods **114** for reciprocating movement in the direction of arrow B, i.e. generally parallel to the direction of movement of side member **14**. A motor **120** reciprocates plate **116** in the direction of arrow B via a rod **122** connected to the plate **116**.

Four die-carrier rods **118** extend slidably through the plate **116** in a direction generally perpendicular to rods **114**. The female die **106** is mounted on the ends of rods **118** at the open side of housing **112**. Thus, as rods **118** slide in the plate **116**, the die **106** is reciprocated toward and away from the sheet material in a direction generally transverse to the direction of movement of the sheet material. The ends of rods **118** distal the die **106** are provided with flanges **124**. A compression spring **126** is mounted between each of the flanges **124** and the plate **116** whereby the rods **118** and attached die **106** are normally biased away from the side member **14**.

A pair of brackets **128** extend from plate **116** toward die **106**. Rotatably carried by the brackets **128** is a cam shaft **130**. Shaft **130** is mutually perpendicular to both rods **118** and rods **114**. Fixedly mounted on shaft **130** and spaced along its length are a pair of cams **132** which engage the die **106**. A motor **134** is provided at one end of shaft **130** to rotate the shaft **130** and its cams **132**.

It can be seen that, as the motor **120** reciprocates rod **122**, the plate **116** will be reciprocated in the direction of arrows B, moving first in the same direction as side member **14** and then back in an opposite but parallel direction. Plate **116** will carry rods **118**, die **106**, brackets **128**, cam shaft **130**, cams **132** and motor **134** along with it in this reciprocating movement. Simultaneously, motor **134** will rotate shaft **130** whereby die **106** will be reciprocated toward and away from side member **14** alternately under the influence of the lobes of cams **132** and the springs **126**. The motors **120** and **134** are synchronized so that the die **106** is cammed inwardly during the forward stroke of motor **120**, i.e. that stroke which moves the plate **116** in the same direction as side member **14**. During the return stroke of motor **120**, in which plate **116** is moved in a direction opposite that of side member **14**, die **106** is urged away from member **14** by springs **126**. The speed of motor **120** is also synchronized with that of the fastening assemblies **50**, **98**. Thus the operation of the bead-forming assembly will not interfere with the movement of the side member **14**.

As mentioned above, the left-hand sub-assembly **110** includes a like mechanism for simultaneously reciprocating male die **107** in the direction of arrows B and toward and away from side member **14**. The mechanism for die **107** is synchronized with that for die **106** so that the dies are caused to mate as they move toward side member **14**. Thus the dies deform the sheet material to successively form beads **16** spaced along the length of side member **14**. The fact that both dies **106** and **107** move toward and away from the sheet material of side member **14**, as well as along its direction of travel, further serves to prevent interference with the movement of side member **14**, binding of the sheet material, etc. Furthermore, the sizes and speed of rotation of cams **132** are suitably coordinated with the spacing between the compression struts **22** of the side member so that the beads **16** will be formed on the compression struts.

Turning now to FIGS. **9** and **10**, one form of fastening assembly is shown. The assembly of FIGS. **9** and **10** is a rotary type fastening assembly and includes two sub-assemblies **136** and **138**. The rotary type fastening assembly is primarily intended to be used in the column-forming assemblies for the purpose of fastening the sheet material of each spiral column **12** upon itself, in which case one of the sub-assemblies **136** or **138** would be disposed in the mandrel **52** in the position diagrammatically indicated by **94**, and the other sub-assembly would be disposed at **96** (see FIGS. **5** and **6**). As will be explained more fully below, the assembly can also be used to join the sheet material for the type of column shown in FIG. 2A. However, with suitable structural modifications to prevent crushing of the beads **16**, the basic principles of the rotary-type fastening assembly could be applied to the fastening of the side members to the columns.

The sub-assemblies **136** and **138** include respective framework members **140** and **142** respectively. Framework member **140** has thickened block portions **140*a***, and framework member **142** has opposing thickened block portions **142*a***. Portions **140*a*** and **142*a*** define a passageway therebetween, for overlapping layers of sheet material **144**, **146** to be joined, and serve to support and guide the sheet material. Sub-assembly **136** has a driven disc **148** rotatably mounted thereon by a shaft **150** keyed to disc **148** by a key **152** and extending through framework **140** to a drive motor **154**. Disc **148** has a plurality of sockets **156** extending radially thereinto. In each socket **156** a respective punch element **158** is secured by a pin **160**. Block portions **140*a*** are arcuately configured distal the sheet material **144**, **146** to receive the disc **148** and are further provided with arcuate recesses **162** to permit passage of the punch elements **158**.

Sub-assembly **138** has a second disc **164** journalled on a shaft **166** by a bushing **168**. Shaft **166** is in turn keyed to framework member **142** by a key **170**. Disc **164** is tangentially opposed to disc **148** and the circular path in which it is moved by motor **154**. During such movement, the punch elements **158** are driven cyclically into and out of an annular recess **172** extending radially into disc **164**. With the layers **144** and **146** of sheet material interposed between the discs **148** and **164**, the circumferential edge surface **174** of disc **164** will serve as a backing surface for the sheet material, while the recess **172** will permit each punch element **158** to pass through the sheet material cutting a pair of aligned holes **176**, **178** in the respective layers **144**, **146** and forming a pair of overlapped tabs **180**, **182** from the respective layers **144**, **146** of sheet material. The trailing side of each punch element **158** is bevelled as indicated at **158*a*** to ensure the formation of a single tab from each layer of sheet material and the positioning of such tabs on the trailing sides of the holes from which they are cut.

As the disc **148** continues to rotate, the element **158** which has most recently cut through the sheet material remains engaged in the holes **176**, **178** and drives the sheet material along in a path tangential to the discs **148**, **164**. By the time that one punch element is withdrawn from the holes it has cut, the following punch element will be sufficiently engaged with the sheet material to

continue driving the same. Thus the assembly provides for continuous drive of the sheet material.

After cutting, the depending tabs **180**, **182** pass through a recess **184** in the adjacent block portion **142***a*. The sheet material next passes between a pair of tangentially opposed rollers **186** and **188** rotatably mounted on respective ones of the framework members **140**, **142** in following relation to the discs **148** and **164**. As the sheet material passes between rollers **186**, **188**, the tabs **180** and **183** are bent back away from holes **176**, **178** upon the main bodies of the layers of sheet material **144**, **146**. The tabs **180** and **182** thus form self-attaching means for holding the layers **144**, **146** together.

For simplicity, the framework members **140** and **142** have been shown as generally rectangular in FIGS. **9** and **10**. However, it will be appreciated that, for purposes of positioning one or the other of the sub-assemblies **136**, **138** within one of the mandrels **52**, it may be necessary to provide a framework member with a partially curved configuration and to position the related disc and bending roller accordingly. Furthermore, the direction of curvature will be determined by the orientation of the sub assembly in the mandrel **52**. Such modifications are well within the skill of the art. It is also noted that, while an idler disc **164** has been provided in the preferred embodiment shown, for the purpose of reducing frictional resistance to movement of the sheet material, a stationary backing member having a recess for receipt of punch elements **158** could be employed.

Referring now to FIGS. **14**, **15**, **16** and **17**, there is shown a second form of fastening assembly having two sub-assemblies **190** and **192** adapted to receive overlapped layers of sheet material **200**, **202** therebetween. The assembly is primarily intended to be used for fastening the side members **14** to the columns **12** (or **12'**) or for fastening the material of columns **12'** (FIG. **3A**) upon itself. When the assembly is used for fastening a side member to a column member, its sub-assemblies are disposed in positions **50** and **98** respectively illustrated in FIG. **7**. It would also be possible, with suitable structural modifications, to apply the basic principles of the assembly of FIGS. **14–17** to the joining of the material of the spiral wound columns **12**.

Sub-assembly **190** includes a housing **194** having a first solenoid assembly **196** mounted therein. The solenoid assembly **196** includes a rod **198**, which is moved toward the sheet material **200**, **202** when the solenoid coil **204** is energized. Solenoid assembly **196** further includes a mounting block **206** and a compression spring **208** to return the rod **198** in a direction away from the sheet material when the coil **204** is de-energized in the well known manner.

The end of rod **198** closest to the sheet material **200**, **202** is sharpened to form a punch element **210**. Thus the solenoid assembly **196** is operative to reciprocate the punch element **210** toward and away from the sheet material. The wall of housing **194** adjacent the sheet material has a slot **212** therein to permit the punch **210** to pass outwardly through the housing and into the sheet material **200**, **202** to cut a pair of aligned holes therein. A similar slot **215** is provided in the opposite housing wall distal the sheet material to receive the blunt end of rod **198** when the latter is in its retracted position.

Both slots **212** and **214** are elongated in a direction transverse to the direction of reciprocation of rod **198**, and the entire solenoid assembly **196** is mounted for reciprocation in such transverse direction. In particular, mounting block **206** is slidably mounted in housing **194** and is secured to one end of the rod **216** of a second solenoid assembly **218**. Solenoid assembly **218** has a mounting block **220** which is fixedly mounted in housing **194**.

When the coil **222** of solenoid assembly **218** is energized, the attached solenoid assembly **196** is held in a position distal assembly **218** as illustrated in FIG. **14**. When coil **222** is de-energized, the spring **224** of solenoid assembly **218** moves rod **216** and attached solenoid assembly **196** toward solenoid assembly **218**, i.e. in a first direction generally parallel to the sheet material and transverse to the direction of reciprocation of rod **198**. This brings the solenoid assembly **196** to the position illustrated in FIG. **15**. Housing **194** has an aperture **226** for receipt of the rod **216** during such movement. Then when coil **222** is again energized, rod **216** and solenoid assembly **196** are returned to the position of FIG. **14**, i.e. moved in a second direction opposite to the first direction mentioned above.

Mounting block **220** has, on the side adjacent the sheet material **200**, **202**, a flange **228** projecting toward solenoid assembly **196**. A die member **230** is mounted on the flange **228** and extends into an opening **232** in the housing **194** whereby it is exposed to the sheet material **200**, **202**. The mounting block **206** is undercut at **206***a* to receive flange **228** when solenoid assembly **196** moves toward solenoid assembly **218**.

The other sub-assembly **192** includes a framework **234** in which is mounted a third solenoid assembly partially shown at **236**. Solenoid assembly **236** is arranged so that, when its coil is not energized, its rod **238** is urged toward sheet material **200**, **202** and sub-assembly **190** by a compression spring, and when its coil is energized, rod **238** is drawn away from sub-assembly **190**, in the well known manner. A plate **240** is mounted on the end of rod **238** adjacent the sheet material for sliding movement toward and away from the sheet material in the framework **234**.

Plate **240** carries first and second die members **242** and **244** respectively. First die member **242** is cylindrical having a planar annular support surface **242***a* adjacent sheet material **200**, **202**. Thus, when rod **238** is extended toward the sheet material as shown in FIG. **13**, die member **242** supports the sheet material whereby the punch **210** can pass through the sheet material and into the bore of die member **242**. Accordingly a pair of aligned holes **245** are formed in the respective layers of sheet material **200**, **202** with a plurality of pairs of overlapped tabs **246** of sheet material circumferentially spaced about the periphery of each such pair of holes and depending from the main bodies of the sheet material.

Second die member **244** cooperates with die member **230** (hereinafter referred to as the third die member) to bend the tabs **246** back upon (i.e. in overlying relation to) the main bodies of the sheet material to fasten the layers together. The surface of die member **244** facing sheet material **200**, **202** serves as the bending surface for bending back the tabs **246** and includes a central projection **244***a* whose apex is rounded and whose sides flare outwardly from the apex to the base. The bending surface further includes an annular concavity **244***b* surrounding the base of projection **244***a*. Projection **244***a* is positioned to register with one of the pairs of aligned holes **245** which has been formed by punch **210** and also with a concavity **230***a* in the opposed surface of third die member **230**. When die member **244** is moved

toward die member **230** by the spring of solenoid assembly **236**, the free edges of tabs **246** are engaged by the projection **244***a* near its apex, then spread apart by the flared sides of projection **244***a*, and finally curled or folded back upon the main bodies of the sheet material by the concavity **244***b*, as shown in the finished fasteners at the right in FIGS. **14** and **15** and also in FIG. **16**.

The die member **230** is recessed at **230***b* over an area including concavity **230***a* and slightly larger than the holes **245**. Thus, as die member **244** is brought into engagement with the sheet material, the main bodies of the sheet material adjacent the aligned holes **245** are deformed into the recess **230***b* thereby forming a slightly upset rim **247** around each such pair of holes. This increases the strength of the finished fasteners. Thus the surface of die member **230** including concavity **230***a* and recess **230***b* serves not only as a support surface for the bending action of die member **244**, but also as a bending surface in and of itself.

The sequential operation of the three solenoid assemblies can best be understood by reference to FIG. **17** in conjunction with FIGS. **14** and **15**. Such operation is cyclical, each cycle including five steps. FIG. **17** represents only one simplified example of means for effecting such cyclical operation, and it will be apparent that numerous other means, including solid state electronics systems, could be employed.

As indicated in FIG. **17**, the sequencing means includes a control panel or station for the entire truss-forming apparatus. By closing a switch **250** on panel **248**, a circuit is completed via leads **252** and **254** to a motor which rotates a shaft indicated at **256**. Shaft **256** is operatively connected to a rotor **258**. Closing a switch **250** also supplies current through line **262** to a conductive ring on which are mounted five switches **266**, **268**, **270**, **272**, and **274**. Each of the latter switches is electrically connected to one or more of three lines **278**, **280**, and **282** which are in turn connected to the coils of respective solenoid assemblies **196**, **218**, and **236**. Switches **266–274** are normally open. When mechanically closed by engagement with rotor **258**, each switch completes a circuit or circuits to the connected solenoid or solenoids.

When rotor **258** is engaged with switch **266**, solenoid assembly **218** is energized whereby solenoid assembly **196** is held in a position distal solenoid assembly **218**, i.e. in a position such that punch **210** is aligned with die member **242**. Solenoid assembly **196** is de-energized so that punch is retracted from the sheet material **200**, **202**, and solenoid assembly **236** is also de-energized so that die members **242** and **244** are engaged with the sheet material. Switches **266–276** are symmetrically spaced about rings **264**, and rotor **258** is sized so that its leading edge will engage each switch just before or substantially simultaneously with the disengagement of its trailing edge with the preceding switch.

As rotor **258** engages switch **268**, solenoid assembly **218** remains energized to hold punch **210** in alignment with die member **242** and solenoid assembly **236** remains de-energized to retain die member **242** in a position supporting the sheet material. Solenoid assembly **196** is energized to effect a stroke of punch **210** through the sheet material and into the bore of die member **242**. This position of the assembly is illustrated in FIG. **14**.

As rotor **258** engages switch **270**, all three of the solenoids are energized. Thus punch **210** is retained in a position in alignment with die member **242** and in engagement with the pair of aligned holes which it has just formed in the two layers of sheet material. However, die member **242** is retracted from the punch and the sheet material to permit subsequent lateral movement of the punch **210** to advance the sheet material. The latter movement is effected where rotor **258** engages switch **272**, retaining solenoid assemblies **196** and **236** in energized condition, but permitting de-energizing of solenoid assembly **218** whereby the entire solenoid assembly **196** with punch **210** still engaged in the sheet material is drawn toward solenoid assembly **218**. This position of the apparatus is shown in FIG. **15**. It will be noted that during this step, the tabs **246** adjacent the holes formed prior to those currently engaged by the punch are brought into alignment with die members **230** and **244**.

Closing of switch **274** by rotor **258** permits solenoid assembly **196** to de-energize to retract punch **210** from the sheet material. Upon re-engagement of switch **266** by rotor **258**, punch **210** is retained in the retracted position, while solenoid assembly **218** is energized to return solenoid assembly **196** to a position distal solenoid assembly **218** where punch **196** is once again aligned with die member **242**. Simultaneously, solenoid assembly **236** is de-energized bringing die member **244** into engagement with the aligned tabs **246** to fold back said tabs and deform the adjacent portion of the main bodies of the sheet material into the recess **230***b* of die member **230**. This also brings die member **244** into a supporting position with respect to the sheet material so that it is ready for the next stroke of the punch **210**.

Thus the fastening assembly of FIGS. **14** and **15**, as operated by the sequencing means of FIG. **17**, is, like the fastening assembly of FIGS. **8** and **10**, operative not only to progressively fasten overlapped layers of sheet material together but also to advance the sheet material. It is also noted that the spacing between die members **242** and **244** permits beads **16** of side member **14** to be received therebetween so that the side members may be joined to the column members of the truss without crushing the beads **16**.

The various assemblies described above, when incorporated into the complete truss-forming apparatus shown in FIG. **4**, may be powdered by any suitable means, such as electric motors, as is well known in the art. Furthermore, the speeds of operation of the various assemblies will be synchronized to permit smooth, continuous operation of the entire apparatus. As mentioned above, the mechanisms for forming the three columns **12** are preferably provided with respective variable speed motors **76** (see FIG. **4**). By monitoring deviations of the progressing truss from a straight path, and then selectively varying the speeds of the motors **76**, such deviations can be corrected before they advance beyond a negligible degree to produce a virtually straight truss. Electric, electronic or other means may be provided to automatically vary the speeds of the appropriate ones of the fastening assemblies in accord with the speed variations of the motors **76** so that smooth operation will continue at all times.

Referring once again to FIG. **1**, there is diagrammatically illustrated one means of monitoring deviations of the truss **10** from a straight path. A transmitter **284** is mounted on or beneath the truss-forming apparatus for transmitting a laser or other beam **286** along the desired centerline of the truss **10**. Beam **286** in effect serves as a stationary or reference target. An endpiece **288** is mounted on the free end of truss **10**. At the center of endpiece **288** is a target point **288***a* which is movable

with the free end of the truss **10**. The relative positions of beam **286** and target point **288***a* can be monitored by means well known in the art. It is then merely necessary to vary the speeds of the motors **76** so as to maintain beam **286** and point **288***a* in alignment.

FIG. **1** also indicates that the truss **10** is being deployed from the oribiting vehicle **26** in the direction of the earth E. Thus the slight amount of force which is exerted on the truss **10** by the earth's gravitational field is utilized to further guide the truss **10** in a straight path as it is formed and deployed.

Referring finally to FIGS. **3A** and **18–20**, there is shown an alternate form of truss and apparatus for forming the columns thereof. As best seen in FIG. **3A**, the truss **10'** is generally triangular in transverse cross-sectional configuration having three columns **12'** interconnected by side members **14**. Side members **14** are substantially identical to the like numbered members of the truss **10** of FIGS. **2** and **3**. However, columns **12'** differ from columns **12** in both general configuration and method of formation.

Each column **12'** is generally teardrop shaped in transverse cross-sectional configuration and is oriented with its apex facing laterally outwardly with respect to the truss **10'** as a whole. A respective flange portion **12***a* extends outwardly from the apex of each column for use in connecting the truss **10'** to other structural members. The columns **12'** are formed by a technique commonly known as "roll forming" in which a strip of sheet material is curved around a mandrel to bring portions adjacent its side edges into juxtaposition. These side portions are then secured together.

To form the columns **12'**, apparatus such as is illustrated in FIGS. **18–20** may be incorporated into the device shown in FIG. **4** in place of the column-forming assemblies **32**. The apparatus of FIGS. **18–20** includes an outer support cylinder **290** which would be mounted on the plate **39** (FIG. **4**). Three mandrels **292** are disposed within cylinder **290** parallel thereto and are mounted on cylinder **290** by spacers **294**.

A respective reel **296** is mounted below and radially inwardly of each mandrel **292** on brackets **298** extending to plate **30**. Each reel **296** contains a rolled strip of sheet material **300** oriented generally tangentially to the respective mandrel **292**. The lower portion of each mandrel **292** is enclosed by a housing **302** having open upper and lower ends and mounted on cylinder **290**. A roller **304** is mounted on the bottom of each housing at its radially inner side to guide the respective strip of sheet material **300** into the open lower end of housing **302**.

Within the housing **302** are a number of rollers, one which is indicated at **304**, for beginning to curve the sheet material **300** around the mandrel **292**. Above the uppermost one of the spacers **294**, a pair of rollers, one of which is shown at **306** are rotatably mounted on cylinder **290** to direct the sheet material **300** further around the mandrel **292**. Roller **306** has a cylindrical end portion **306***a*, as does a similar roller on the other side of mandrel **292**, for forming flanges **300***a* adjacent the side edges of the sheet material **300** (see FIG. **20**). These rollers bring the sheet material **300** almost completely around the mandrel **292** but allow a sufficient gap between the flanges **300***a*, beginning to form therebelow, to permit the sheet material to pass the uppermost spacer **294** (see FIG. **20**).

Just upwardly of the roller **306**, a fastening assembly, which may be of the type shown in FIGS. **9** and **10** or the type shown in FIGS. **14** and **15**, is mounted on the cylinder **290**. One of the sub-assemblies of the fastening assembly is shown at **308**, and the other sub-assembly is similarly mounted in an opposed position on the other side of flanges **300***a* of the sheet material. The fastening assembly brings the flanges **300***a* into abutment and fastens them together to form the flange portion **12***a* of the resulting column **12'**.

Above the fastening assemblies, including sub-assembly **308**, there would be a suitable framework mounting rolls of pre-cut sheet material for side members **14** and bead-forming assemblies such as shown in FIGS. **12** and **13**. Above the latter assemblies would be the fastening assemblies, shown in FIG. **19** and the upper part of FIG. **18**, for fastening the side members **14** to the columns **12'**. Each of these fastening assemblies includes one sub-assembly **310**, mounted on the interior of a cylinder **312**, which is in turn mounted at the upper end of the supporting framework (not shown) for the aforementioned bead-forming assemblies. The other sub-assembly **314** of the pair is disposed within the respective mandrel **292**. Each assembly **310**, **314** is thus positioned to secure a respective one of the attachment elements **18** of the side members **14** to the adjacent one of the columns **12'**.

From the foregoing detailed description it can be seen that the present invention provides a method and automated apparatus for forming structural members which are uniquely suited for use in space. Although the sheet material from which the structural members are formed is extremely light, flexible and thin, the resulting structural members are capable of withstanding tremendous compressive loads and may be used to construct large orbiting structures.

For example, a single column of the teardrop form (FIG. **3A**) was constructed from 0.012 in. (0.03 cm.) gauge aluminum. This specimen was 12 in. (30.48 cm.) in length and approximately 1.50 in. (3.81 cm.) wide (measured from side to side rather than from apex to base). The sheet material was fastened upon itself with 7 self-attaching fasteners of the type shown in FIG. **16**, spaced approximately 1.50 in. (3.81 cm.) apart. This specimen withstood compressive loads up to 1000 lbs. (4450 nt.).

A complete truss segment of the type shown in FIG. **3A** was similarly tested. This specimen included side members of 0.008 in. (0.02 cm.) gauge alumnium and columns of 0.012 in. (0.03 cm.) gauge aluminum. The specimen was 72 in. (182.9 cm.) in length and 24 in. (60.96 cm.) wide on each side. This specimen withstood compressive loads up to 1580 lb. (7031 nt.).

Thus the present invention provides a practical expedient for the construction of large space structures, such as orbiting solar collectors. By using a basic sheet material which is lightweight and readily compacted, it is possible to carry enough material to construct a large number of long structural units in a single trip of the transport vehicle. The use of the self-attaching fasteners also reduces bulk and weight by eliminating the need to transport separate fastening means. Furthermore, the formation of such fastening means produces no chips or other debris or wasteful by-products. The precutting of the material for the side members further reduces the weight of the material while also enhancing the uniformity of thermal expansion of the finished unit. Furthermore, the apparatus may be fully automated thereby requiring minimal extra-vehicular activity by the oper-

ating personnel. Numerous other advantages inherent in the invention as described above will be evident.

It can further be appreciated that various modifications of the embodiments described above may be made without departing from the spirit of the invention. By way of example only, where a suitable plastic sheet material is used in place of aluminum, it might be secured upon itself by a heat fusion technique, rather than by the use of the tab-type fasteners disclosed above. It is also noted that terms such as "upwardly," "downwardly," "above," etc. have been used herein merely for convenience and with reference to the positions in which the apparatus appears in the drawings and are not intended in a limiting sense with regard to any actual positions in use. It is therefore intended that the scope of the invention be limited only by the claims which follow.

I claim:

1. A method of manufacturing in situ a structural member from compactly stored flexible single sheet material comprising:

(a) progressively forming a plurality of generally tubular column members, each by advancing sheet material from an independent source into a column forming assembly, and deploying the column members generally parallel to one another;

(b) interconnecting adjacent column members simultaneously with the forming thereof by progressively securing a respective side member between each such pair of adjacent column members each side member being comprised of a strip of the sheet material advanced from an independent source.

2. The method of claim 1 wherein each of said side members includes a pair of opposite side edges and is oriented with each such side edge disposed adjacent a respective one of the column members interconnected by said side member.

3. The method of claim 2 wherein the securing of said side members to said column members includes forming selfattaching fasteners of the sheet material of said column members and side members.

4. The method of claim 3 wherein the sheet material of the side member adjacent each of said side edges is positioned adjacent the respective column member to form overlapping layers of the sheet material of said side member and said column member, said securing including punching through said overlapping layers to form overlapping tabs of said sheet material depending from the main bodies of said sheet material, and bending said tabs back upon the main bodies of said sheet material.

5. The method of claim 2 wherein the sheet material of each of said side members is compacted in the form of a roll prior to formation of said structural member and deployed from such roll during formation of the structural member.

6. The method of claim 5 wherein the sheet material of each of said side members is pre-cut to form, a pair of attachment elements extending longitudinally along said side edges for securing to said column members, a plurality of strut elements extending transversely between said attachment elements, and a plurality of open spaces between said attachment elements and strut elements.

7. The method of claim 6 wherein at least some of said strut elements are formed generally perpendicular to said attachment elements to serve as compression struts.

8. The method of claim 7 including sequentially forming elongate beads on each of said side members, each of said beads being formed to extend between the side edges of said side member along a respective one of said compression struts and being formed prior to securing the adjacent portions of said attachment elements to said column members.

9. The method of claim 7 wherein others of said strut elements are formed diagonally with respect to said attachment elements and compression struts to serve as tension struts.

10. The method of claim 1 wherein each of said column members is formed from a respective strip of said sheet material closed upon itself.

11. The method of claim 10 wherein three of said column members are formed.

12. The method of claim 10 wherein the sheet material of each of said column members is compacted in the form of a roll prior to formation of said column member and is deployed from such roll during formation of the column member.

13. The method of claim 10 including fastening the sheet material of each of said column members upon itself to form said column member by forming self-attaching fasteners of the sheet material of said column member.

14. The method of claim 13 wherein said fastening includes disposing portions of the sheet material of each of said column members in overlapping layers, punching through said overlapping layers to form overlapping tabs of said sheet material depending from the main body of said sheet material, and bending said tabs back upon the main body of said sheet material.

15. The method of claim 10 wherein each of said columns is formed by helically winding the respective strip of sheet material.

16. The method of claim 10 wherein the strip of sheet material of each of said column members includes a pair of opposite side edges, and wherein each of said columns is formed by rolling said strip of sheet material to bring said side edges into juxtaposition.

17. The method of claim 1 being performed in space.

18. The method of claim 17 including providing a reference target and forming and deploying said structural member in the direction of said target.

19. The method of claim 18 including selectively varying the speeds of formation of said column members to maintain said structural member in alignment with said target.

20. The method of claim 19 including sensing a movable target mounted on and movable with said structural member and varying said speeds to maintain said targets in alignment.

21. The method of claim 17 including forming and deploying said structural member toward the earth.

22. The method of claim 1 using aluminum as said sheet material.

23. Apparatus for manufacturing in situ a structural member from compactly stored flexible single sheet material comprising:

a plurality of storage means adapted to receive the flexible single sheet material in compacted form;

column-forming means for progressively forming a plurality of tubular column members each by advancing sheet material from one of said plurality of storage means and deploying said column members generally parallel to one another;

means for progressively positioning a respective side member between adjacent column members simultaneously with the forming thereof, each side member being comprised of a strip of the sheet material advanced from one of said plurality of storage means;

and connecting means for progressively securing each side member to the adjacent column members.

24. The apparatus of claim **23** wherein said storage means comprise storage reels for receiving said sheet material in roll form.

25. The apparatus of claim **24** including a separate one of said storage reels for each of said column members and side members.

26. The apparatus of claim **23** wherein said column-forming means includes a respective column-forming assembly for each of said column members, each of said column-forming assemblies comprising means for closing a respective strip of said sheet material upon itself to form the respective column member.

27. The apparatus of claim **26** wherein each of said column-forming assemblies is operative to helically wind the respective strip of said sheet material.

28. The apparatus of claim **27** wherein said storage means comprise a separate storage member for the strip of sheet material of each of said column members, and wherein each of said column-forming assemblies comprises a stationary mandrel, guide means for directing the respective strip of sheet material from the respective one of said storage members onto said mandrel, and means mounting said storage member and said guide means for rotation about said mandrel to helically wrap said strip of sheet material on said mandrel.

29. The apparatus of claim **26** wherein the strip of said sheet material of each of said column members includes a pair of opposite side edges, and wherein each of said column-forming assemblies is operative to roll said strip of said sheet material to bring said side edges into juxtaposition.

30. The apparatus of claim **26** wherein each of said column-forming assemblies includes a fastening assembly for fastening the sheet material of the respective column member upon itself by forming self-attaching fasteners of the sheet material of said column member.

31. The apparatus of claim **30** wherein each of said column-forming assemblies is operative to dispose portions of the respective strip of sheet material in overlapping layers, and wherein said fastening assembly includes punch means for punching through said overlapping layers to form overlapping tabs of said sheet material depending from the the main body of said sheet material, and bending means for bending said tabs back upon the main body of said sheet material.

32. The apparatus of claim **31** wherein said punch means is carried by a rotary carrier disposed generally tangentially to said overlapping layers of said sheet material.

33. The apparatus of claim **31** wherein said punch means is mounted for reciprocation generally into and out of said overlapping layers of said sheet material.

34. The apparatus of claim **33** wherein said punch means is further mounted for movement in a path generally transverse to the direction of said reciprocation while engaged in said overlapping layers to advance said sheet material.

35. The apparatus of claim **26** wherein each of said column-forming assemblies includes a column drive assembly, the speeds of said column drive assemblies being individually selectively variable to vary the speeds of formation of said column members.

36. The apparatus of claim **23** wherein each of said side members includes a pair of opposite side edges, and wherein said positioning means is operative to orient each of said side members with each of its side edges adjacent a respective one of the column members to be interconnected by said side member.

37. The apparatus of claim **36** wherein said connecting means comprises a plurality of fastening assemblies, each for securing a respective side of a respective one of said side members to the adjacent one of said column members by forming self-attaching fasteners of the sheet material of said column member and said side member.

38. The apparatus of claim **37** wherein said positioning means is operative to position the sheet material adjacent each of said side edges adjacent the respective column member to form overlapping layers of the sheet material of said side member and said column member, and wherein said fastening assembly includes punch means for punching through said overlapping layers to form overlapping tabs of said sheet material depending from the main bodies of said sheet material, and bending means for bending said tabs back upon the main bodies of said sheet material.

39. The apparatus of claim **38** wherein said punch means is carried by a rotary carrier disposed generally tangentially to said overlapping layers of said sheet material.

40. The apparatus of claim **38** wherein said punch means is mounted for reciprocation generally into and out of said overlapping layers of said sheet material.

41. The apparatus of claim **40** wherein said punch means is further mounted for movement in a path generally transverse to the direction of said reciprocation while engaged in said overlapping layers to advance said sheet material.

42. The apparatus of claim **31** further comprising bead-forming means operative to sequentially form a series of elongate beads on each of said side members, each of said beads being formed to extend between the side edges of the respective side member and prior to securing of the adjacent portions of said side member to said column members by said connecting means.

43. The apparatus of claim **42** wherein said bead-forming means includes a plurality of bead-forming assemblies each associated with a respective one of said side members, each of said bead-forming assemblies including opposed first and second die members having said side member interposed therebetween, first drive means for simultaneously reciprocating said die members toward and away from said side member, and second drive means for advancing said die members in a first direction generally parallel to said side member when said die members are engaged with said side member and for retracting said die members in a second direction generally opposite said first direction when said die members are disengaged from said side member.

44. The apparatus of claim **42** wherein said die members have mating arcuate cross-sectional configurations for forming arcuate beads.

45. A structural member comprising:

a plurality of tubular, generally parallel column members formed of flexible sheet material,

a plurality of respective side members, each comprised of a strip of sheet material interconnecting adjacent pairs of the column members, each of said side members including a pair of longitudinally extending attachment elements secured to respective ones of the connected pair of column members, and strut elements extending transversely between said attachment elements, with open spaces between said attachment elements and strut elements, and wherein at least some of said strut elements are disposed generally perpendicular to said attachment elements to serve as compression struts, and

wherein each of said compression struts has an elongate bead extending therealong and through the adjacent portions of said attachment elements, and

first self-attaching means connecting each side member to the adjacent column members and formed by the members connected.

46. A structural member according to claim **45** wherein said beads are of arcuate cross-section configuration.

47. A structural member according to claim **45** wherein others of said strut elements are disposed diagonally with respect to said attachment elements and compression struts to serve as tension struts.

48. A structural member according to claim **48** wherein the sheet material of each of said side members overlaps the sheet material of the connected column members, and wherein said first self-attaching means include overlapping tabs of said sheet material cut from the main bodies of said overlapping sheet material and folded back upon the main bodies.

49. A structural member according to claim **51** wherein each of said first self-attaching means includes a plurality of pairs of said overlapping tabs radiating from a common pair of aligned apertures in the main bodies of said overlapping sheet material.

50. A structural member according to claim **48** wherein each of said column members is comprised of a respective strip of sheet material closed upon itself.

51. A structural member according to claim **50** wherein the sheet material of each of said column members is fastened upon itself by second self-attaching means formed by said column member.

52. A structural member according to claim **51** wherein the sheet material of each of said column members forms overlapping layers, and wherein said second self-attaching means include overlapping tabs of said sheet material cut from the main body of said overlapping sheet material and folded back upon said main body.

53. A structural member according to claim **52** wherein each of said second self-attaching means includes a plurality of pairs of said overlapping tabs radiating from a common pair of aligned apertures in said overlapping sheet material.

54. A structural member according to claim **50** wherein the sheet material of each of said column members is helically wound.

55. A structural member according to claim **50** wherein the strip of sheet material of each of said column members includes a pair of opposite side edges, said strip of sheet material being rolled so that said side edges are juxtaposed.

56. A structural member according to claim **55** wherein each of said column members is generally teardrop-shaped in transverse cross section.

57. A structural member according to claim **56** wherein said column members are oriented such that the apexes of said teardrop shapes face laterally outwardly, and wherein each of said side members is disposed generally tangentially to the connected column members.

58. A structural member according to claim **57** wherein the strip of sheet material of each of said column members has flange portions adjacent to and including said side edges and extending laterally outwardly from the apex of said teardrop shape.

59. A structural member according to claim **48** wherein said sheet material is aluminum.

60. A structural number according to claim **45** wherein there are three of said column members.

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